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Standard for Shunt Capacitor

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Capacitor

What is Capacitor function in Power System?

- Supplying reactive power in system and mitigating effects of inductive reactance
- Improve Power Factor
- Reduce the Voltage Drop

Why inductive reactance occurs in high volume in system?

- Most of our industrial, commercial, and residential loads are inductive in nature

Capacitor Element

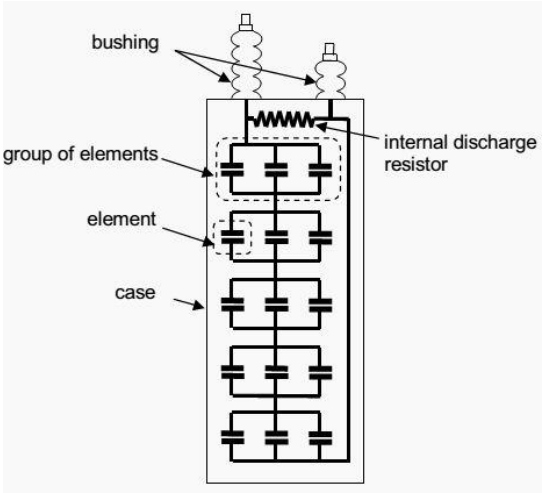
The basic component of capacitor unit , have dielectric between two electrodes

Capacitor Unit

It composed of capacitor elements(horizontal or vertical mounting), bus bars, dischargers, connector and Fuses.

Discharge device

It is needed while we need to disconnect our capacitor from power system, it mitigates the trapped or residual current after shutting off capacitor bank from Power system

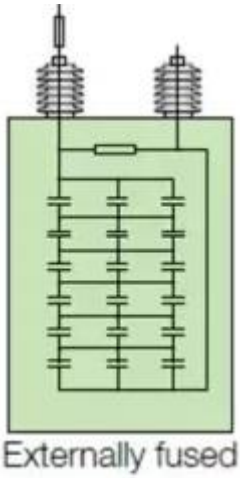


What is the purpose of Fuse in capacitor?

It helps in isolate only faulty capacitor unit or element or group from power system rather than complete capacitor bank

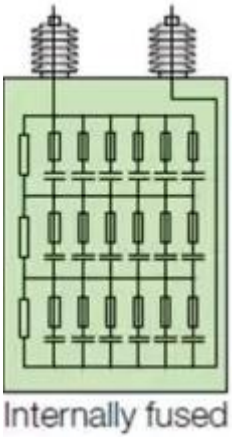
Externally fused capacitor bank

Capacitor with External fuses, it is easy to replace damaged fuses but it is expensive as compare to internally fused capacitor bank. It's application(that is why it is cheaper than internally fused capacitor) is limited to Low Reactive power(few KVAr)



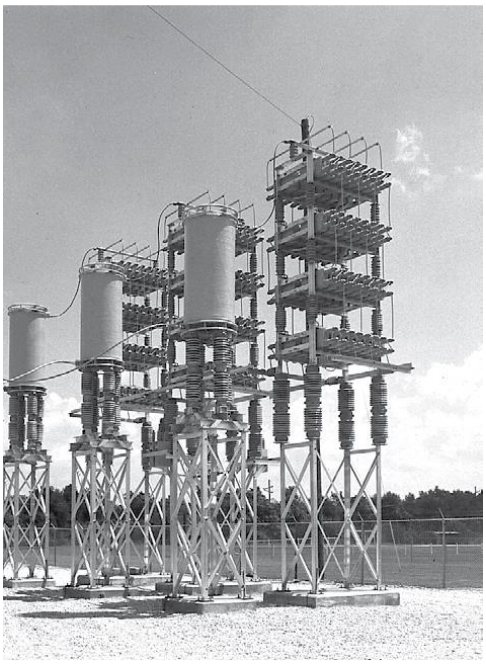
Internally fused capacitor bank

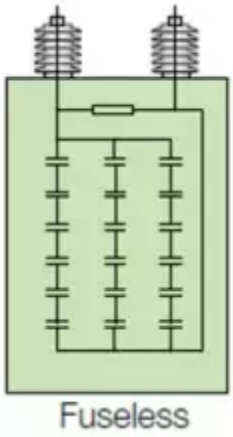
Simply where Reactive power is more to mitigate as compare to externally fused capacitor bank, or that one capacitor element has a capacity about the same value as a unit had previously it is reasonable to protect each separate element with an internal fuse.



Fuse less Capacitor Bank

Suitable for voltage level 34.5KV and above, in it all capacitor elements are connected in series to form group or string, these strings are then connected in parallel to form unit.





How Capacitor Rated?

On the bases of

- R.M.S Terminal to Terminal Voltage
- Terminal to case or Ground insulation class
- Reactive Power
- Number of phases
- Frequency

Capacitance tolerance

Allowable tolerance $\leq 10\%$

Capacitor Operational value limits

- Operational Voltage $\leq 110\% \; of \; rated \; R.M.S \; voltage$
- Peak Voltage $\leq 1.2 \sqrt{2} V_{Rated \; RMS}$(excluding transient values)
- Operational Current $\leq 135 \; \% \; of \; I_{nominal \; RMS}$
- 135% of rated KVAR

Typical voltage and reactive power ratings for capacitors

Volts, rms (terminal-to-terminal)	kvar	Number of phases
216	5, 7 1/2, 13 1/3, 20, and 25	1 and 3
240	2.5, 5, 7 1/2, 10, 15, 20, 25, and 50	1 and 3
480, 600	5, 10, 15, 20, 25, 35, 50, 60, and 100	1 and 3
2400	50, 100, 150, 200, 300, and 400	1 and 3
2770	50, 100, 150, 200, 300, 400, and 500	1 and 3
4160, 4800	50, 100, 150, 200, 300, 400, 500 and 600	1 and 3
2400	50, 100, 150, 200, 300, and 400	1 and 3
2770	50, 100, 150, 200, 300, 400, and 500	1 and 3
4160, 4800	50, 100, 150, 200, 300, 400, 500 and 600	1 and 3
6350, 6640, 7200, 7620, 7960, 8320, 9540, 9960, 11 400, 12 470, 13 280, 14 400	50, 100, 150, 200, 300,400, 500, 600, 700, and 800	1
15 125, 15 920	50, 100, 150, 200, 300,400, 500, 600, 700, and 800	1
19 100, 19 920	100, 150, 200, 300, 400,500, 600, 700, and 800	1
20 800, 21 600, 22 800, 23 800, 24 940	100, 150, 200, 300, 400,500, 600, 700, and 800	1

Insulation classes

For above mention table values

$$30Kv \leq BIL \leq 200Kv(only\ for\ outdoor\ Capacitors)$$

Note: Not all BIL and voltage ratings are applicable to two bushing capacitor units

Frequency

50 or 60 Hz

Ambient temperature

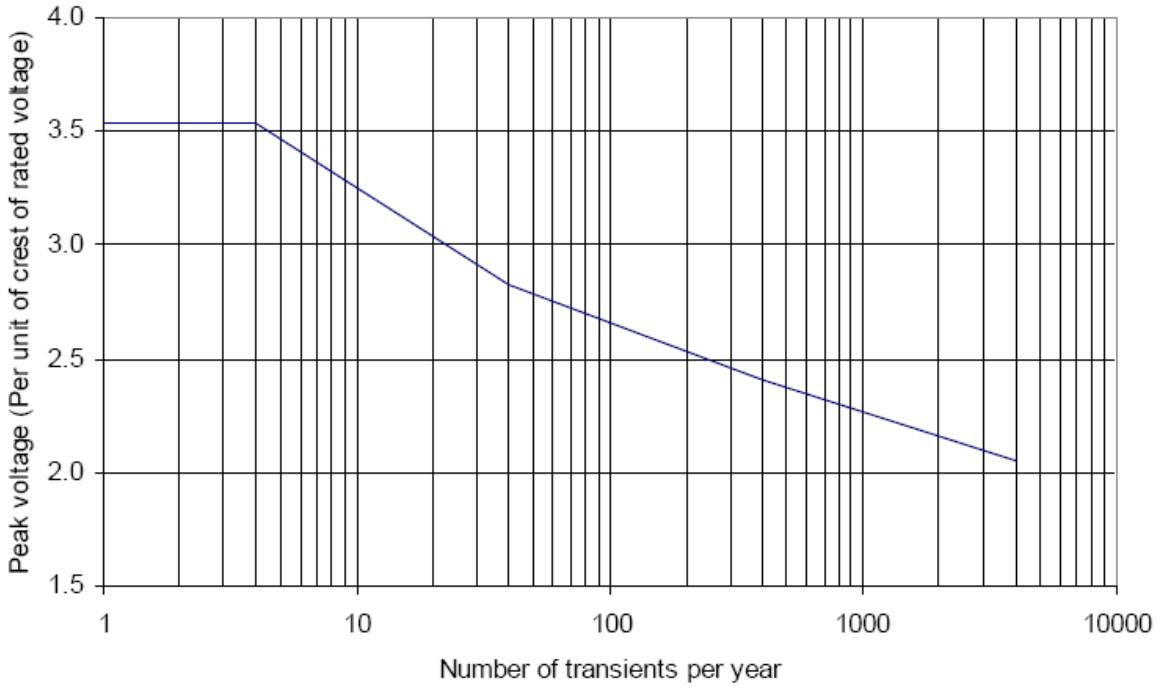
For 24 hours,

$$46°C \leq Maximum\ Average\ Ambient\ Temperature \leq 55°C$$

$$-50° \leq Minimum\ Ambient\ Temperature \leq -40°C$$

Overvoltage withstand

Overvoltage withstand $\leq 2\ times\ peak\ capacitor\ rated\ Voltage$, The continuous and short time overvoltage capabilities of any capacitor element of a capacitor unit shall be considered to be its share of the total unit voltage capability.
For shunt Capacitor



Transient peak overvoltage capability of capacitor units

In Figure, the curve is based on straight line segments between the following points on semi-log coordinates:
(1.0, 5/√2), (4.0, 5/√2), (40, 4/√2), (400, 3.4/√2) and (4000, 2.9/√2).

Transient Current

For frequent back-to-back capacitor bank switching, peak capacitor unit current should be held to a lower value as indicated in Figure given below

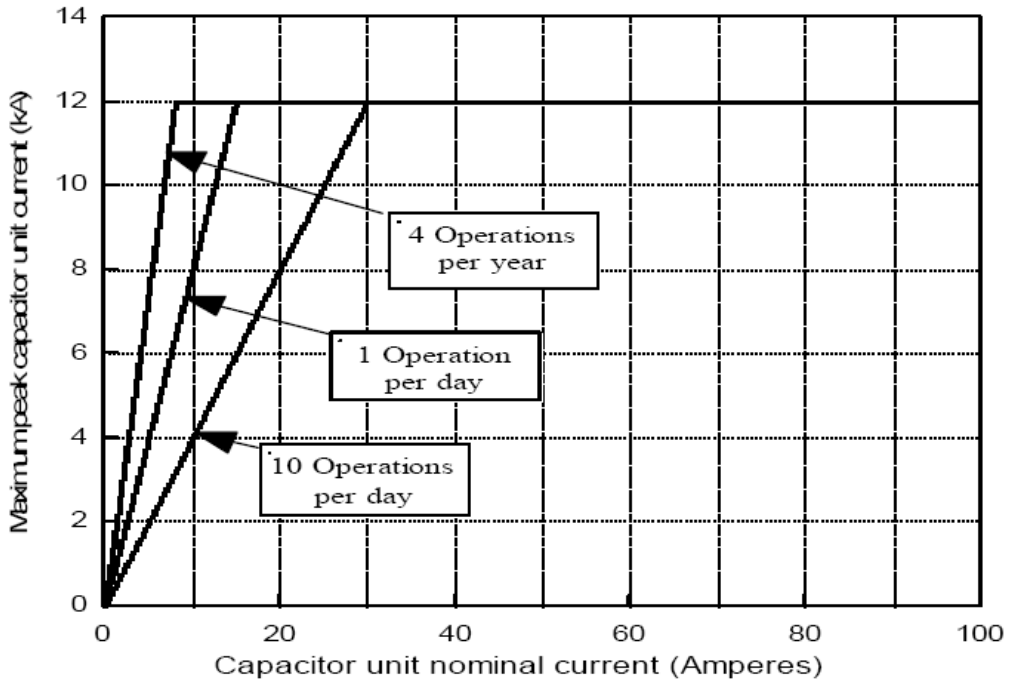


Figure Transient current capability of capacitor units for regularly occurring transients

Manufacturing- Thermal Stability

Ambient temperature shall be 25°C ± 10 °C

Manufacturing Basic impulse insulation level

Minimum impulse levels

Range of capacitor voltage ratings (terminal to terminal) V, rms	Minimum BIL (kV)
216–1199	30[a*]
1200–5000	75[a*]
5001–15 000	95
15 001–20 000	125
20 001–25 000	150

[a]Not applicable to 216 V–5000 V indoor capacitors or housed equipment.

Internal discharge devices (IDD)

After capacitor disconnection from system. IDD will maintain residual voltage ($V_{residual} \leq 50V$), within the following time limits specified in Table

Table Zero **Discharge times**

Range of capacitor voltage ratings (terminal to terminal) V, rms	Maximum time limit (minutes)
600 V or less	1
Over 600 V	5
NOTE—The use of a discharge device should not be considered as a substitute for the recommended practice of manually discharging the residual stored charge before working on capacitors.	

Radio influence voltage (RIV)

$$RIV \leq 250\ micro\ voltage$$

Number of bushings

- Single Phase Capacitor – 1 or two bushings
- 3 Phase Capacitor-3 or 4 bushings

Electrical Characteristics

Table A – Electrical characteristics of bushings

BIL (kV)	Minimum insulation creepage distance		Withstand test voltage [a]		
	mm	inches	50 Hz or 60 Hz [b] Dry 1 min, kV, rms	50 Hz or 60 Hz [b] Wet 10 s, kV, rms	Impulse 1.2/50 µs full wave kV crest
30	51	2	10	6	30
75	140	5.5	27	24	75
95	250	10	35	30	95
125	410	16	42	36	125
150	430	17	60	50	150
200	660	26	80	75	200

[a] Withstand test voltages are for standard temperature and humidity at mean sea level.

[b] The frequency of the 1 min and 10 s tests will be dependent on the power supply available at the manufacturer's facility.

Terminal size

Outdoor capacitors shall be provided with the following types of terminals, as specified by the user:
a) Clamp connector to accommodate a minimum range of conductor sizes from Number 8 solid through Number 2 stranded, AWG; or
b) Threaded stud with 3/8 in x 16 or 1/2 in x 13 threads suitable for bolting directly to bus bars or
c) Threaded stud with M12 or M16 (metric) threads suitable for bolting directly to bus bars.

Single-bushing outdoor capacitors shall have the bushing terminal mention above,

Indoor capacitors shall be provided with terminals consistent with current-carrying requirements in NFPA 70

Metal-enclosed capacitor equipment

A bushing, cable, or conduit entrance shall be provided for outdoor metal-enclosed capacitor equipment rated above 600 V.

Operational factors of Internal fuses for internally fused capacitors

- the discharge energy from elements or units connected in parallel with the faulty element or unit; or
- b) the power frequency fault current

Fuse Disconnecting requirements

Fuse disconnect in voltage range; voltage range is defined by below mention equations

Lowest Voltage between terminal at Fault=V1=0.9*√2*VR

Highest instantaneous Voltage between terminal at Fault=V2=2.0*√2*VR

Fuse Withstand requirements

- After operation Withstand Voltage=Full element Voltage+ any unbalance voltage in any element+ any short time transient voltage
- Withstand current= (maximum permissible current/number of parallel elements in each series section)
- Fuse must withstand inrush switching current
- Fuse of undamaged elements must carry the discharge current which is due to breakdown of elements connected in parallel with them
- Fuse must withstand during external short circuit faults on bank within defined voltage range (V1, V2)

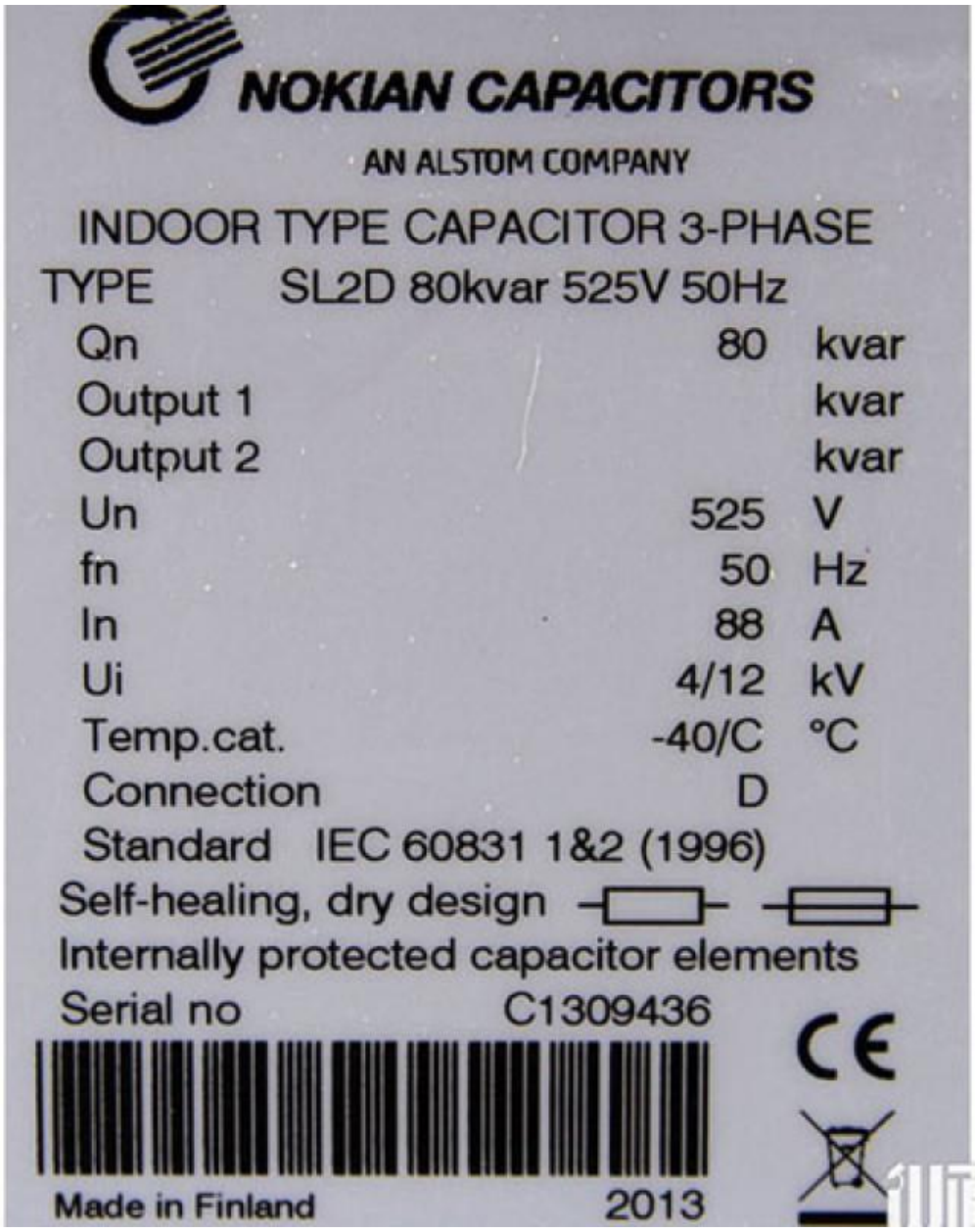
Information-Nameplate-capacitor unit

- a) Name of manufacturer
- b) Unique serial number
- c) Manufacturer's type, model, style, or catalog number
- d) Year of manufacture
- e) Rated reactive power, kVAr
- f) Rated voltage, V rms.
- g) Nominal or measured capacitance, µF.
- h) Number of phases

NOTE—For Y-connected 3-phase capacitors, indicate whether neutral is connected to the case.

- Rated frequency
- BIL (if applicable). For capacitors having bushings with two different BIL ratings, the nameplate shall show both BIL ratings, e.g., 150/95 kV BIL.
- Flammability classification
- Volume of insulating fluid

- Statement that capacitor contains an internal discharge device
- Statement that capacitor contains an internal or external fuse
- In case of internal fuse Capacitor, number of series connected group of parallel elements must mention
- In case of internal fuse Capacitor, maximum number of operations must be mention
- In case of fuse less Capacitor, numbers of series groups must be mentioned



Non-PCB impregnant identification

Additional marking (decal or stick-on label) shall be visible from the ground. A blue marking shall be used to designate non-polychlorinated biphenyl (non-PCB) liquid.

Dimension- Mounting hole spacing

Capacitor Rated	Voltage	Mounting hole Spacing	Between center of Minimum diameter holes
50KVAr to 600KVAr	2.4KV or higher	397 mm ± 1.6 mm (15 5/8 in ± 1/16 in)	11.1 mm (7/16 in)
More than 600KVAr	2.4KV or higher	Agreed by Manufacturers and client	

Note: Cantilever-mounted capacitors (both brackets on one surface of the capacitor case) shall accommodate M16 (or 5/8-in) mounting bolts at 457.2 mm ± 1.6 mm (18 in ± 1/16 in) between centers.

Dimension- Non-enclosed substation equipment

The dimension for the width of the rack, from the center-line to center-line of the rack support insulators, shall be 914.4 mm (36 in).

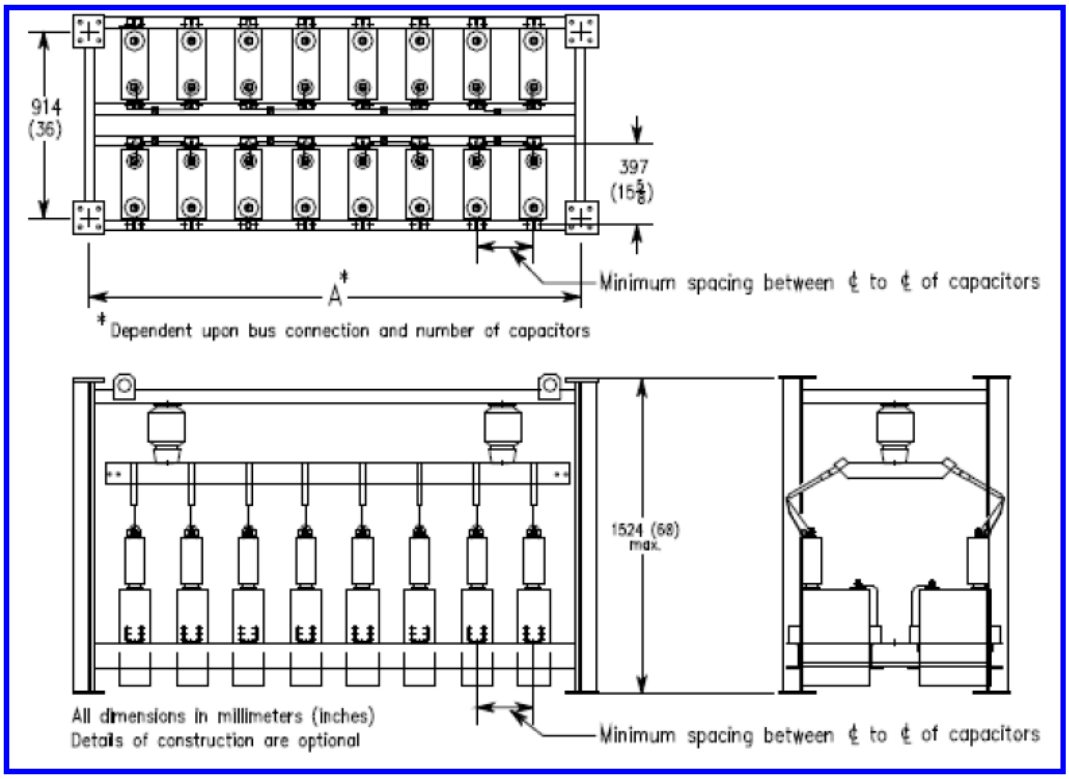


Figure 1 —Dimensions, minimum spacing between and of capacitors for upright mounted, externally fused capacitor banks

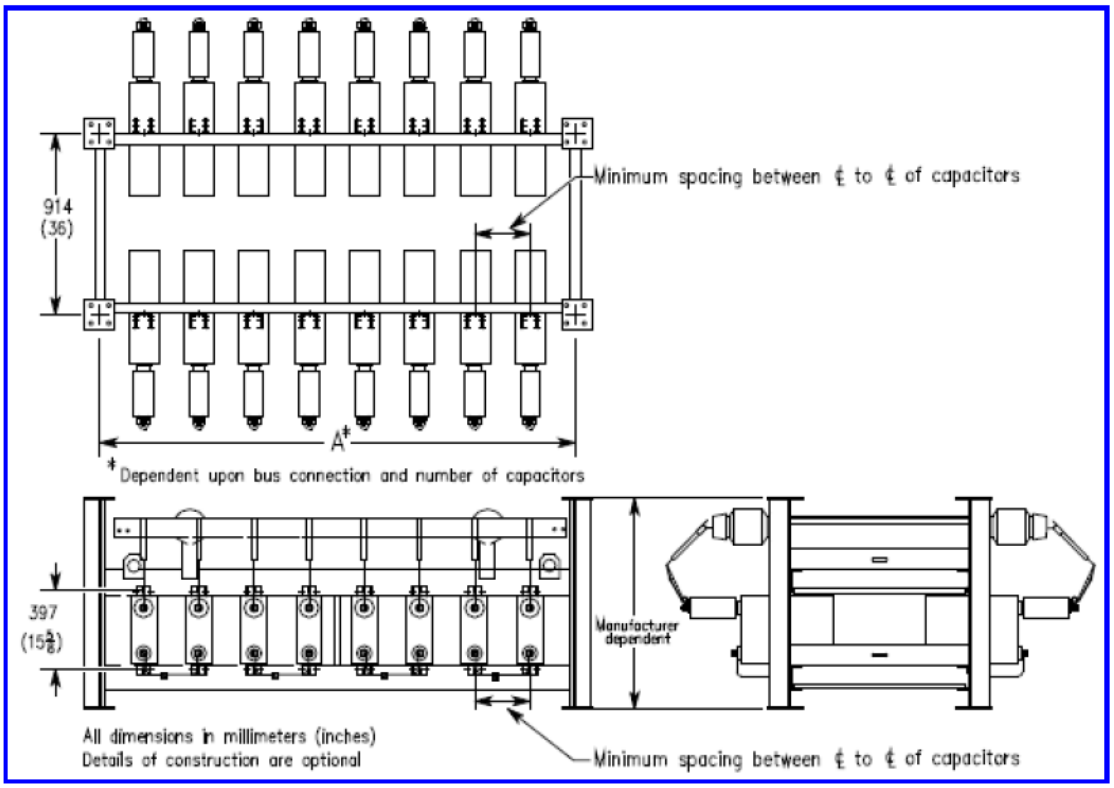
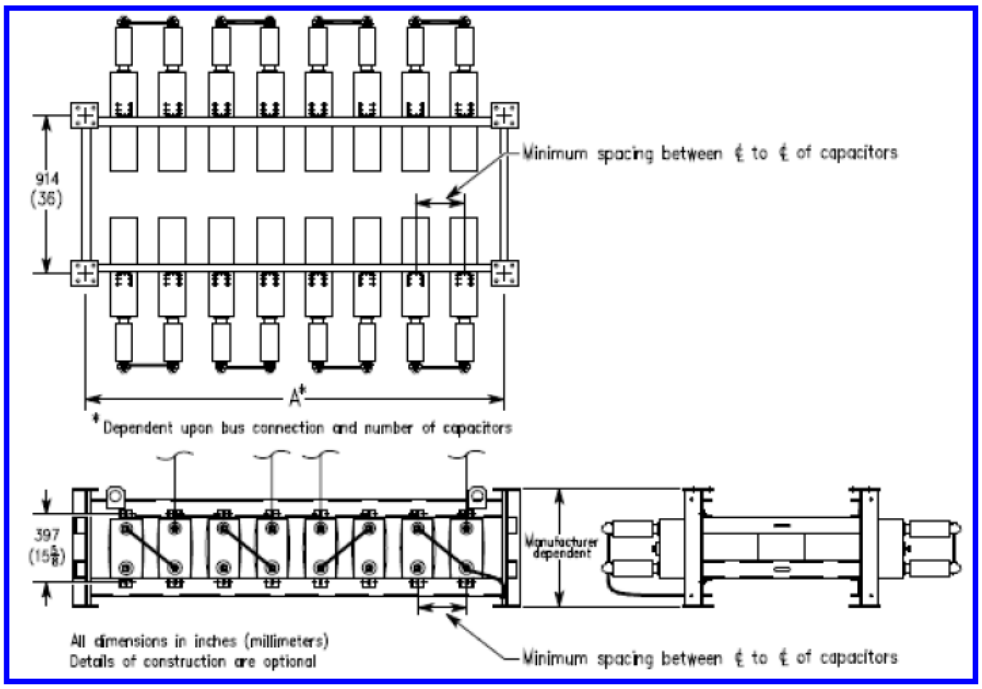


Figure 2 —Dimensions, minimum spacing between and of capacitors for edge mounted, externally fused capacitor banks



(New)

Figure 3 —Dimensions, minimum spacing between and of capacitors for edge mounted, internally fused and fuseless capacitor banks

The dimension for the length of the rack will be dependent upon bus connections and the number of capacitors mounted in the rack

Capacitor Type	Height
Fuse less Capacitor	Agreed by Manufacturers and client
Internally fused Capacitor	Agreed by Manufacturers and client
Externally fused Capacitor	Maximum 1524 mm (60 in)

Number of holes of rack support insulator is agreed by manufacturers and client

Dimension-Minimum spacing between capacitors

Table —Minimum spacing between capacitors

Capacitor Voltage Rating (terminal to terminal) V, rms	Minimum Spacing Between Center-line to Center-line of Capacitors, mm (in)
2400—8000	203.2 mm (8 in)
8001—15000	228.6 mm (9 in)
15001—25000	279.4 mm (11 in)

Electrical bonding Grounding provisions

Capacitors shall have provision for effective electrical bonding of the case to capacitor hangers or mounting frame.

Color

Capacitor Cases and bushing Color shall be light grey (Munsell Notation 5.0BG 7.0/0.4)

Testing

Basic Requirement of Testing

- Frequency 50Hz or 60Hz
- Ambient Temperature 25°C ± 10 °C

Tolerances

- ± 0.5% for frequency
- ± 0.5% for duration
- ± 2.5% for voltage
- ± 1.0 °C for Temperature

Which Capacitor need to be Tested?

- All new Capacitors
- Used in preventive maintenance or client requirement or after repairing work

Design Test-Impulse Withstand Test

- Short two terminals of two bushing Capacitors
- Apply impulse Test Voltage between Shorted terminals and Case

Table B —Test voltages *

Range of capacitor voltage ratings (terminal-to-terminal) V, rms	BIL (kV crest)	Terminals-to-case test voltage ac voltage (50 Hz or 60 Hz) kV, rms	
		Indoor or housed equipment	Outdoor
216–300	30*	3	10
301–1199	30*	5	10
1200–5000	75*	11	26
1200–15 000	95	—	34
1200–20 000	125	—	40
1200–25 000	150	—	50
1200–25 000	200	—	60

*Outdoor units only.

Single bushing Capacitor shall not be subjected to the Impulse withstand test.

Impulse waveshape

The impulse voltage shall be 1.2/50 μs full wave, the tolerance on the crest value shall be ± 3%.

Impulse polarity

The capacitor shall successfully withstand three consecutive positive impulses.

Impulse measurement

The time to crest of a 1.2/50 μs impulse wave shall be measured as 1.67 times the time for the voltage to rise from 30% to 90% of crest value. The tolerance on the time to crest shall be ± 30%. The time to 0.5 crest value point on the tail of the wave shall be measured from the virtual time zero and shall be 40 μs to 50 μs. The virtual time zero shall be taken at the intersection of the zero-voltage line and a line drawn through points on the front of the wave at 30% and 90% of the crest value.

AC voltage test

Two bushing capacitors shall pass the ac voltage tests as indicated in Table A for the applicable BIL rating of the unit (nameplate rating). If no flashover or internal electrical breakdown occurs, it shall be considered as having passed the test successfully.

Thermal stability test

if the hot-spot case temperature reaches and maintains a constant value within a variation of 3 °C for a minimum of 24 h, then capacitor consider thermally stable

this test will be conducted by sampling method, two same values capacitors will be employed as barriers capacitors. Resistor models having the same power loss, thermal characteristics, and physical dimensions as the test capacitor may be substituted for the barrier capacitors.

Thermal stability test method

Mounting conditions

Test Capacitor in enclosure placed with minimum recommended center-center spacing. Test Capacitor position is as per the manufacturer recommendation, aim is to produce maximum internal temperature.

Ambient temperature

Maintained Average Temperature of Air without forced circulation= 46 °C

Inside wall temperature = ± 5 °C of enclosure ambient temperature

Temperature will be monitored by thermocouple; all temperature measurements shall be accurate to within ± 1 °C.

Test voltage

$$V_T = 1.1\ V_R \sqrt{\frac{W_M}{W_A}}$$

This voltage shall be maintained constant, within ± 2% throughout the last 24 h of the test period.

$$V_T = Test\ Voltage$$

$$V_R = Capacitor\ Rated\ Voltage$$

$$W_M = Manufacturer's\ minimum\ allowable\ Power\ Loss\ at\ rated\ voltage\ and\ frequency$$
$$= 110\% V_{rated} * Capacitance_{measured} * PF_{measured}$$

$$W_A = Actual\ Power\ loss\ of\ Capacitor\ at\ rated\ voltage\ and\ frequency$$
$$= 110\% V_{rated} * Capacitance_{actual} * PF_{Test\ Capacitor}$$

Radio influence voltage (RIV) test

The test voltage shall be of rated frequency and 115%, ±5%, of rated voltage rms of the capacitor

Case must be grounded; Test Voltage must be applied between all bushing and grounded case. Capacitors having only one bushing per phase with the

case as the other terminal should not be tested, as this type of construction precludes any meaningful RIV measurement due to the high capacitance.

The RIV, when measured in accordance with the foregoing at a frequency of 1 MHz, shall not exceed 250 µV.

Precautions

a) The capacitor shall be at approximately the same temperature as the room in which the tests are made.
b) The capacitor bushings shall be dry and clean.
c) The capacitor shall be mounted in its recommended position with the manufacturer's recommended minimum clearance between the live parts and grounded surfaces.

Short circuit discharge test

Purpose is to verify the integrity of the internal connections and conductors of the capacitor operating under normal service conditions.
One unit shall be charged to a dc voltage 2.5 times rated rms voltage and then discharged. It shall be subjected to five such discharges. Before and After the five discharges, the terminal-to-terminal capacitance shall be measured at rated low voltage and frequency. The difference in capacitance between the initial and final measurements shall be less than an amount corresponding to either the shorting of an element or operation of an internal fuse.
The discharge circuit shall have no inductive or resistive devices included. The discharge device may be a switch or spark gap and may be situated up to one meter from the capacitor such that the total perimeter of the external discharge loop is less than 3 m. The conductors used to connect the capacitor to the discharge device shall be of copper and shall have a cross-section of at least 10 mm2.

Performance test-Overvoltage test

The test sample ratings shall be no less than 30 kVAr, the test sample shall be conditioned for no less than 12 hours at no less than its rated voltage. After the test, the capacitance of the test sample shall be measured at its rated voltage and frequency. The ambient temperature range for the conditioning test shall be +15 °C to +35 °C.
Steps are given below

a) Place test sample in cold chamber for no less than 12 hours at the intended low temperature ambient (—40 °C unless otherwise specified).

b) Remove and place test sample in still air at an ambient in the range of +15 ° C to +35 °C. Within 5 min after test sample is removed from the cold chamber, apply 110% of rated voltage. Within5 min after the voltage application, apply 225% of rated voltage for 15 cycles without any voltage interruption after which the 110% of rated voltage is maintained without any voltage interruption. After an interval of 1.5 to 2 min, the 225% of rated voltage will again be applied and the process repeated until a total of 150 applications are completed for 1 day

c) Repeat steps a) and b) above for 1 more day. The combined application of the 225% rated

voltages shall be 300 total.
d) Within 30 min of completion of step c) above, proceed to apply 140% of rated voltage for total 96 hours. The test ambient temperature shall be at +15 °C to +35 °C.
e) Measurement of capacitance shall be repeated at rated voltage and frequency

The acceptance criteria are that no break down will occur during test

Validity of test-Dielectric design limits

a) The tested elements shall have the same or fewer number of layers of solid materials in the dielectric and be impregnated with the same fluid.

b) Both, the rated element voltage and the electrical stress level of the tested element shall be equal or higher.

c) The aluminum-foil (electrode) inside edge design shall be the same.
d) Element connections shall be of the same type, for example soldering, crimping, etc.

Test unit design limits

a) Test elements meeting the requirements of Dielectric design limits shall be similarly assembled, have equal or thinner inter-element insulation, and be equally pressed within the manufacturing tolerance, as compared with the units to be manufactured.
b) At least four of these test elements shall be connected to give not less than 30 kvar output at rated voltage (60 Hz). All connected elements shall be placed adjacent to each other and at least one inter-element insulation shall be assembled (must have at least two series groups of elements).
c) A container to the manufacture's standard design shall be used and the size shall be no less than 50% of the height, width and depth of the unit to be produced. (The exact case size shall be agreed upon between the manufacturer and the purchaser.)
d) The drying and impregnation process shall be identical with the normal production process.
e) The test unit shall in all other respects have the same components, such as type of discharge resistors and internal fuses, and follow the same manufacturing procedure as the units to be produced.

Fuse disconnect test for internally fused capacitors

Tests will be done on capacitor on single or more unit, depend on agreement between manufacturer and client.

Test procedures

The disconnecting test on fuses shall be performed at the lower voltage limit of 0.9 VR voltage and at the upper voltage limit of 2.5 VR.
If the test is carried out with dc, the test voltage shall be √2 times the corresponding ac test voltage.
If the test is carried out with ac, the triggering of the element failure with a voltage peak shall not be necessary for the test at the lower voltage limit.

NOTE—The upper voltage limit of 2.5 VR, defined as Vu, is considered to be the minimum required

value acceptable for safe operation of the fuses under a capacitor bank trip condition. The actual upper voltage limit required is dependent upon the capacitor bank protective scheme and the internal element arrangement. The number of failed elements allowed by the manufacturer, before trip signal activation is reached, determines the level of overvoltage to consider for the upper voltage limit.
Vu = 1.5*Vp (3)
Where Vp is the maximum overvoltage that will be impressed on an individual element in a capacitor unit just after the last fuse operation allowed by the bank protection scheme. This fuse is usually considered as part of a subsequent fuse operation in the same parallel group. Vp should be agreed upon between the manufacturer and the user. The 1.5 factor is related to the potential overvoltage during breaker operation for a phase-to-ground fault with an ungrounded capacitor bank.

Capacitance shall be measured after test, in which fuse will be blown off.

Voltage test across the open fuse

dc voltage of 3.5 times the element voltage for 10 s across the broken-down element and the gap in its blown fuse. During the test, the gap shall be in the impregnant. No breakdown over the fuse gap or between any part of the fuse and any other part of the unit is allowed.

Inspection of the unit

Before opening, no significant deformation of the container shall be apparent. After opening the container, a check shall be made to verify that:
a) No significant deformation of sound fuses is apparent;
(b) No more than one additional fuse (or one-tenth of fused elements directly in parallel) has been damaged (see B.1). If method B.2.2 given in Annex B is used, B.1 shall be observed.

Production Test-Short-time overvoltage test- Terminal-to-terminal test

Test Voltage shall be applied for at least 10sec with internal temperature at 25 °C ± 5 °C.

terminal-to-terminal insulation test at a standard test voltage of either of the following:

a) A dc test voltage of 4.3 times rated (rms) voltage; or
b) An ac test voltage of 2 times rated (rms) voltage.

For three-phase, wye-connected units where there is a neutral bushing or the neutral is connected to the case, the above testing for terminal-to-neutral shall be followed by a test at the √3 times the above standard test voltage between each pair of bushings (not including any neutral bushing) to test the phase-to-phase insulation.
For three-phase, wye-connected units where there is no neutral bushing and the neutral is not connected to the case, the rated voltage is the phase-to-phase voltage of the capacitor unit. In order to test both the phase-to-phase insulation and each leg of the wye at the appropriate voltage, the test voltage shall be 1.16 times the above standard test voltage between each pair of bushings (2 ÷ √3 ≈ 1.16).
For three-phase, delta-connected units, the rated voltage is the phase-to-phase voltage of the capacitor unit. The test voltage shall be the above standard test voltage between each pair of

bushings.
The capacitance shall be measured on each unit both before and after the application of the test voltage. The initial capacitance measurement shall be at low voltage. The change in capacitance, as a result of the test voltage, shall be less than either a value of 2% of the originally measured capacitance or that caused by failure of a single element of the particular design, whichever is smaller.

Production Test- Terminals-to-case test (not applicable to capacitors having one terminal common to the case)

Terminals-to-case tests shall be made on capacitors having all terminals insulated from the case. The appropriate test voltage from Table B shall be applied for at least 10 s between all insulated terminals connected together and the case.

Capacitance test (production test)

Capacitance tests shall be made on each capacitor to demonstrate that it will deliver not less than rated reactive power and not more than 110% of rated reactive power at rated voltage and frequency, corrected to a capacitor case and internal temperature of 25 °C.

Leak test

A suitable test shall be made on each capacitor to ensure that it is free from leaks.

Discharge resistor test

A suitable test shall be performed on each capacitor to ensure that the internal discharge device will reduce an initial residual voltage equal to the √2 times rated voltage rms to 50 V or less in the time limits specified in Table Zero.

Loss determination test

Capacitor losses shall be measured at rated voltage at a frequency of 50 Hz or 60 Hz.
If the loss test is made at a frequency other than the rated frequency of the capacitor unit, the manufacturer shall:
a) Clearly indicate the frequency at which the test was made; and
b) Indicate that the value when measured at the capacitor unit frequency will likely be different.

Fuse capability tests for internally fused capacitors

The fuses shall be able to withstand all production tests of the capacitor in accordance with this standard. Internally fused capacitors shall be subjected to one short-circuit discharge test, from a dc voltage of 1.7times rated voltage through a gap situated as close as possible to the capacitor, without any additional impedance in the circuit.
The capacitance shall be measured before and after the discharge test. The difference between the two measured values shall be less than an amount corresponding to one internal fuse operation.
The discharge test may be made before or after the voltage test between terminals. However, if it is

made after the voltage test between terminals, a capacitance measurement at rated voltage shall be made after the discharge test to detect fuse operation.
If, by agreement with the purchaser, capacitors are accepted with operated fuses, the voltage test between terminals shall be made after the discharge test.
It is permitted that dc charging voltage be generated by initially energizing with an ac voltage having a peak value of 1.7 times rated voltage and disconnecting at a current zero. The capacitor is then immediately discharged from this peak value. Alternatively, if the capacitor is disconnected at a slightly higher voltage, the discharge may be delayed until the discharge resistor reduces the voltage to 1.7 times rated voltage.

Bibliography:

IEEE Standard for Shunt Power Capacitors